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(54) Method of pattern generation

(57) A pattern generation technique is described in which a pattern is produced in a radiation sensitive material by writing only the perimeters of the desired features, and effecting a toning step to define the full pattern. This enables a slow but high resolution technique e.g. electron beam lithography, to be used to define the outline of the pattern 9 in a resist 5. In one embodiment after development of the

resist, removal of the bared underlying chrome layer 3 and removal of the remaining resist a chrome layer with a pattern of ditches defining the features is produced (Figure 4). By differentially etching or plating the layer inside and outside the perimeters the full feature 7 is formed (Figure 5).

Various etching techniques are described including applying different electrical biases to the areas inside and

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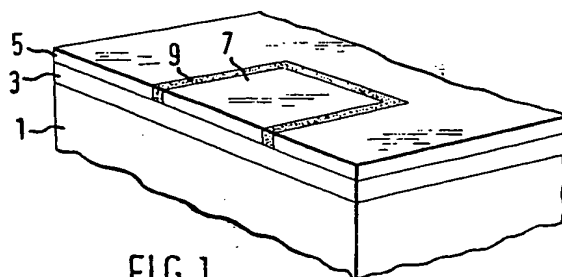


FIG. 1

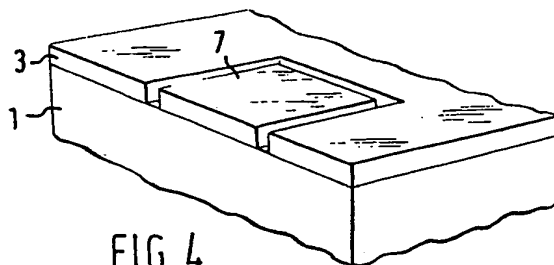


FIG. 4

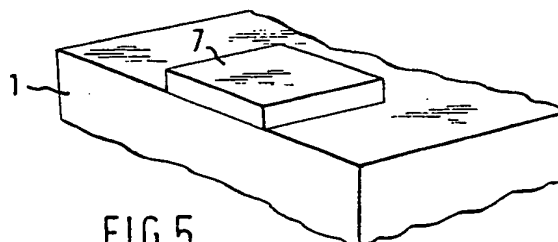


FIG. 5

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outside the perimeters, e.g. by contacting some areas with Al or Ln, before immersion in etchant (dilute HCl). In a second embodiment selected areas are contacted with Cu and the chrome etch is cerium based.

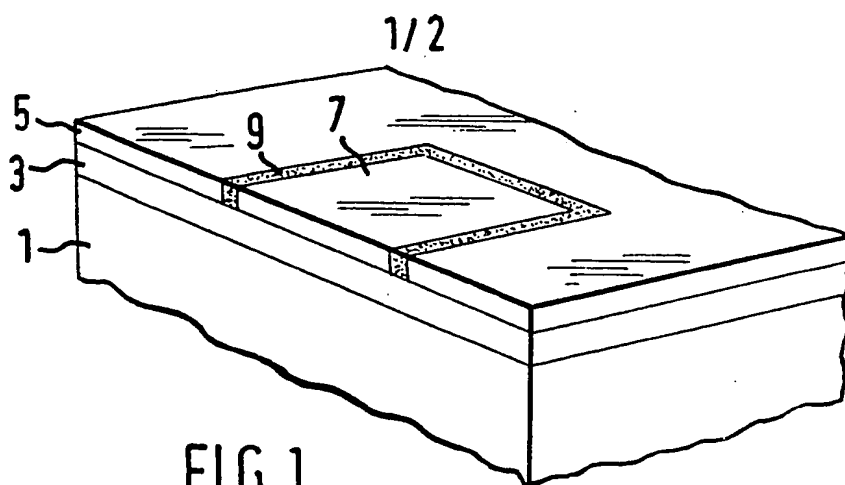


FIG. 1

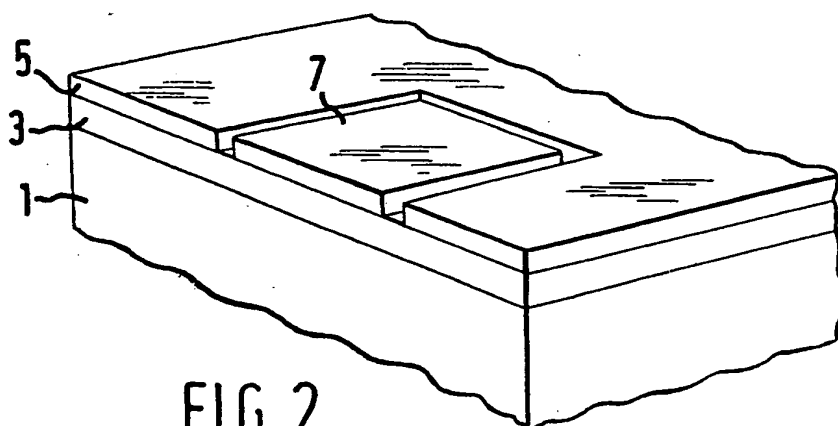


FIG. 2

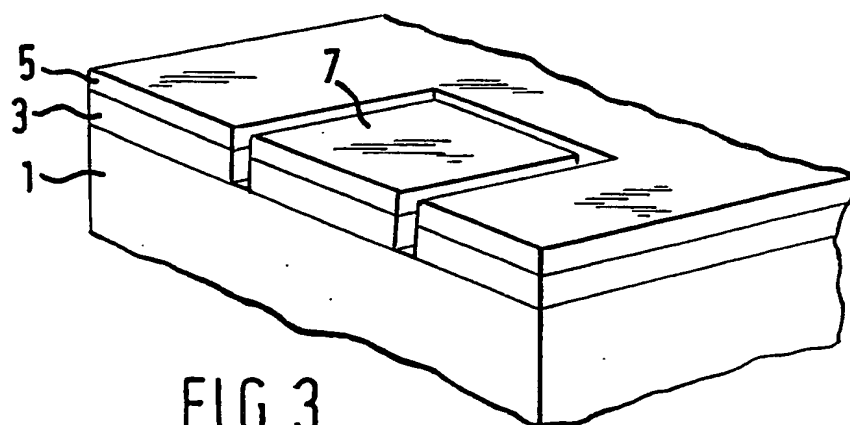
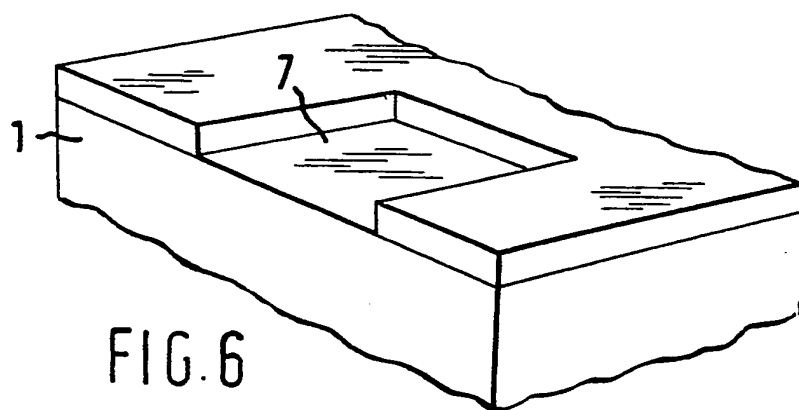
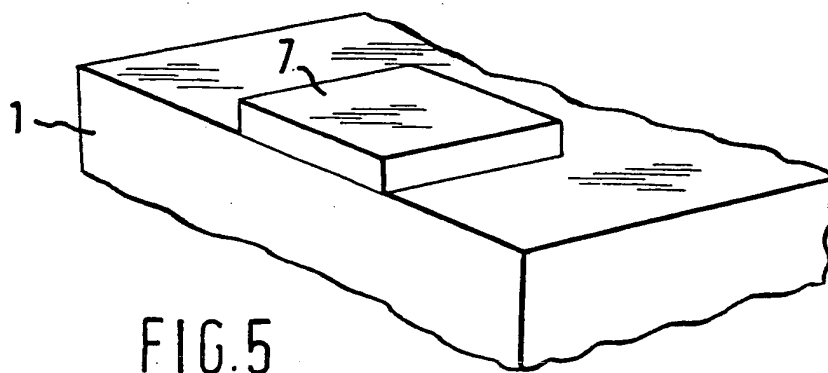
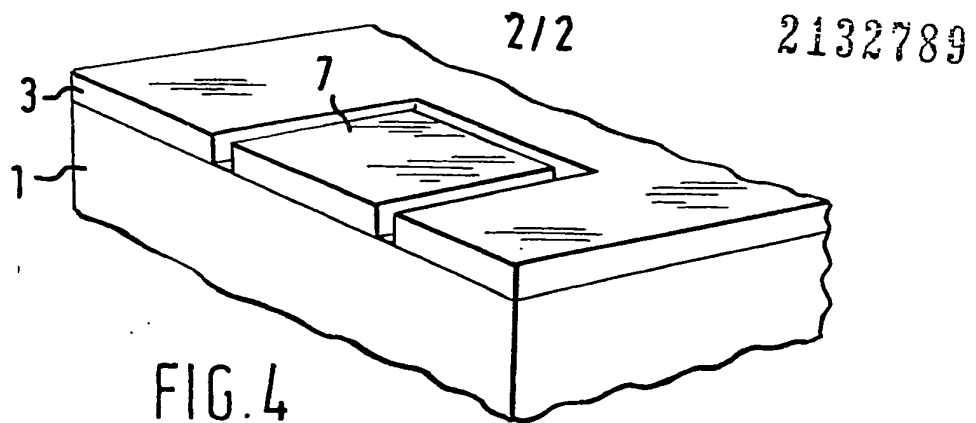


FIG. 3



SPECIFICATION

Method of pattern generation

5 This invention relates generally to pattern generation.

Many aspects of modern technology, such as the fabrication of integrated circuits, require high precision replication or production of patterns. The patterns are typically produced by coating a substrate with a radiation sensitive material, commonly termed a resist, and then exposing selected portions of the resist to radiation which renders the exposed portion either more or less soluble, when subjected to an appropriate developer, than the unexposed portion. After the more soluble portion of the resist has been removed, the now exposed substrate material may be modified by, for example, doping or material removal. The resist is termed negative or positive depending upon whether the exposed portion becomes less or more, respectively, soluble with respect to the unexposed portion. The resist may be exposed directly to the radiation source or a mask may be positioned between the source and the resist.

Several techniques have been developed to accomplish this lithographic replication or production of patterns. For example, photolithography and X-ray lithography have been developed. A third lithographic technique, electron beam lithography, has also been developed. This technique is a high resolution, high precision means of producing patterns for thin film devices and integrated circuits. However, it is generally a serial process, that is, the patterns are written in a step-by-step manner, and writing with this technique is inherently slow and presently expensive. Primarily because of these limitations, electron beam lithography is commonly used only for direct writing of patterns for devices intended for research purposes or when the need for extremely high resolution or precision requires use of this technique. Consequently, at the present time, the primary use of electron beam lithography is the production of precision master masks for photolithography. Photolithography is the technique most commonly used at the present time for device fabrication and the expensive processing of master masks is justified because such masks are presently used to fabricate hundreds, if not thousands, of wafers. The master masks presently used typically have a patterned layer of chrome on a glass substrate.

The limitations previously mentioned regarding speed and cost present in current electron beam lithography techniques may be better understood from the following consideration. When a pattern feature, for example, a rectangle in a positive resist, is written, one conventional exposure approach scans the electron beam in some fashion across the entire area of the feature with the beam remaining at each point or address within the feature for the time required to expose the resist. The time required to write a pattern is then determined by the time required to position the beam for each feature and, for each feature, the time required to expose the

feature. The minimum time required to write a feature, once the beam is positioned, is determined by the scanning speed and/or the dosage required for exposure of the resist to the desired level at the given beam current. Writing speed and required dosage are among the central considerations for development design selection of electron beam lithography machines and resists.

Unless the feature which is to be written has a size comparable to the minimum address size of the particular writing machine being used, consideration of the process just described leads to the realization that much of the writing is redundant as more of the resist is exposed than is absolutely required to accurately define the pattern, i.e., the positions and shapes of the features.

In accordance with the present invention, it has been appreciated that most information regarding the pattern would be adequately conveyed if only the perimeter of each feature were exposed as this defines the position and shape of the feature completely. The tone of the feature, which is ordinarily determined by whether the resist within the perimeter is retained or removed, could be determined by a subsequent processing step.

Therefore, according to the present invention there is provided a method for patterning material on a substrate, said material comprising radiation sensitive material, comprising the steps of defining, by exposing to radiation, at least portions of the material which forms the perimeters of features of said pattern, said defining producing radiation exposed first areas having characteristics differing from those of nonradiation exposed nonperimeter second area, and toning said material, the extent of said toning being limited by said first areas.

The process of exposing only the feature perimeters and selectively toning the interior areas in a subsequent step could reduce the writing time in many cases. Such a writing process might have other advantages. First, for some patterns, the radiation dosage delivered to the substrate will be substantially reduced and advantageous results may be realized. In electron beam lithography, the electrons scatter in both the resist and substrate and the scattering results in background fogging and an effective spatial variation in optimum exposure dose. This deleterious effect, which is commonly termed the proximity effect, should be alleviated for some types of features, for example, two closely spaced and relatively large blocks if only the perimeters of the blocks were written. Moreover, in some cases exposure corrections might be more easily calculated because of the more local nature of the writing process. Furthermore, in direct writing on substrates that are subject to electron damage, a decrease in a real dose may make the writing process more tolerable if only the feature perimeters are exposed. Second, if the tone-controlling process were sufficiently flexible, the same resist might be used for both positive and negative images without significant change in the writing time. Therefore, an optimum resist, selected on various grounds, such as resolution, might be used for either tone pattern.

We have found that a method of patterning a

shown, the perimeter of a feature 7, which is rectangular, has been written in outline on the resist with the written area indicated as 9. The exposure, i.e., the processing step that writes the feature, is conveniently made with a scanning electron beam and alters the characteristics of the exposed areas. The details regarding production and scanning of the beam, beam intensity, etc., are well known to those skilled in the art and need not be described in detail. Other exposure techniques such as a focused ion beam may be used and other geometries may, of course, be written.

The exposed portion of the resist, which is more soluble than the unexposed portion of the resist, is removed in an appropriate and well-known developer to yield the structure shown in Figure 2. The now exposed portion of the chrome layer is removed by, for example, etching, in the exposed region yielding the structure in Figure 3. The remaining resist is then stripped leaving an island 7 of chrome which is isolated from its surroundings by a trench in the chrome film as shown in Figure 4. The steps of exposing portions of the resist to radiation, developing the resist and removing the exposed portion of the chrome layer thus define the perimeter of the feature and comprise the defining step for this embodiment.

The toning step, which alters a characteristic of the material, requires a further etch or other processing step. Toning of chrome may be performed several ways. For example, if the substrate is immersed in diluted HCl and touched with, for example, an aluminum object somewhere outside the perimeter, i.e., at a point outside the trench, a "positive" image of the desired feature, i.e., a chrome rectangle, is produced as shown in Figure 5. Alternatively, use of a well-known cerium-based commercial etchant with continued contact with copper at a point outside the trench produces the "negative" image of reversed tone that is depicted in Figure 6. It will be apparent to those skilled in the art that obvious adjustments in the dimensions of the originally exposed resist pattern are required if precisely identical positive and negative images are to be produced. The structures depicted in Figure 5 and 6 may be used as masks in the pattern delineation of substrates.

The invention is advantageously practiced with the embodiment of the metal film on an insulating surface because there are readily available means of implementing Brush Fire Lithography for this embodiment. For example, the removal of the metal in a narrow stripe defining the perimeter of each feature may be accomplished by any lithographic procedure such as ion beam lithography, followed by sputtering, etc., as well as the electron beam lithography followed by the chemical etching described.

After removal of the perimeter of the features, the now outlined metal or conducting layer features are electrically isolated from their surroundings and as a result, toning processes may be provided which are controlled by, for example, supplying different electrical biases to individual isolated features, i.e. selectively biasing a portion of the electrically conducting layer. This embodiment may be referred to as Electrically Controlled Brush Fire Lithography or,

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joint defect in a resist, produce many embodiments of Brush they are in the interior of a

the intermediate stage in ECBFL has been defined but toning med, there is an opportunity for remedying some defects in a example, the electrical isolation res that are simply-connected serving the pattern by Scanning y (SEM) or some other means electrical potential. When SEM is isolated features will literally "light ging effects. An attempt may air the pattern or the pattern ed at this relatively early stage in before more processing costs are le, if there is a micro short ue to incomplete etching, remove the short. In direct ated circuit, this diagnosis would el of processing, and the pattern, would probably be recoverable. vice processing, the amplifica- h occurs somewhat naturally in hy may be advantageous rather a defect at the edge of a feature ough invisible, in conventional is.

oned, it should be clear to those ECBFL may be extended to the metals or conducting materials substrates, and that the insulate an insulating buffer layer or nducting or partially conducting strates with previous device ited. Such a structure allows the ce patterns by ECBFL or other ecause the final metal pattern k for selective removal of the equent processing of the e.

resent invention is not limited to tching of lines. If a negative off or negative relief process, ose already discussed may be the identical pattern and then ositing metal after development l by resist removal which leaves metal patterns.

fic embodiment described re- ire perimeter of the features, it d that the present invention ing the entire perimeter. For e accidental breaks in the substantially all of the peri- r, i.e., enough of the perimeter ambiguously indicate the ver, enough of the perimeter ovide control of the toning er may also be written with ith internal structures. For ritten twice and have lines and outer lines resulting in a

structure analogous to a sidewalk.

The embodiment described uses electron beam lithography. It should be understood, however, that other radiation can be used advantageously in other 70 embodiments. For example, in the field of lithog- raphy the incident radiation could be, for example, in the form of particles such as electrons, ions, atoms, molecules, or photons, such as those of light or X-rays. The incident radiation could be in the form of 75 focussed single or multiple beams that are focussed to a spot or to a specific shape, e.g., a line segment or rectangle. The pattern of radiation on the sub- strate could also be formed by focussed images, or by shadows cast by a suitable mask. The radiation 80 could be scanned over the radiation sensitive mate- rial so that it is incident in different regions at different times or incident in all desired areas simultaneously.

The effect of the radiation on the radiation sensi- 85 tive material could be, for example, to erode the material, as in physical sputtering or reactive ion etching, to alter its chemical or physical properties, as in the exposure of resists, or even to add material as in ion implantation or material deposition by 90 particles. The radiation might also cause intermixing or chemical reactions between separate compounds of the surface layers.

It should be noted that the material coating the substrate could comprise more than one layer of 95 material. These layers could act singly or in combination to provide the requisite radiation sensitivity and might also aid in defining the tone of the pattern. Additionally, the substrate might be radiation sensi- tive in such a way as to expedite the process, as for 100 example, in the doping of silicon by a focussed ion beam which would change the substrate conductiv- ity to permit subsequent selective electrochemical treatment, e.g., etching, of the surrounded features.

The boundaries may be defined completely by the 105 radiation exposure as, for example, in focussed ion beam etching or additional steps may be required, as for example, in the development of resists. Moreover, several steps may be required to define completely the boundary for purposes of device 110 manufacture as, for example, in the development of resists followed by the removal or alteration of an underlying layer such as the etching of metal films.

Toning, that is, the alteration of a characteristic of the outlined features in the material, can comprise 115 means in which the material in the outlined feature behaves differently from the material outside the feature and which uses the boundary to permit adjacent features to be altered in different ways. Toning may also be stopped by the edge of the 120 material. Electrical means in which the different features are held at different electrical potentials have been described. Other useful techniques for differentiating between features in the toning pro- cess include any substance or phenomenon which 125 propagates through or on the material but which cannot cross a feature perimeter or boundary be- cause the properties of the boundary differ from those of the adjacent material. Propagating subst- ances might comprise diffusing solute atoms, mole- 130 cules or ions, electrical charge or liquids which wet

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more simply, as ECBFL. Such electrical biases may be used in various electrolytic solutions to cause preferential etching, anodization, or electroplating of the differently biased portions of the metal film that were lithographically patterned and outlined.

Additionally, in the specific embodiment of the chrome film on an insulating substrate, the activity of certain etches that are commonly used in etching chrome may be either inhibited or promoted by suitable electrical biases such as may be caused by contact with certain metals while in the etch. For example, when immersed in dilute HCl, chrome films are commonly found to be protected by a passivation layer that is either initially present or formed in the HCl and which will not etch. This behaviour reflects the well-known phenomenon of passivity in chrome and other metals. Physical and electrical contact during immersion with an active metal, for example, Al or Zn as previously mentioned, conveniently provides an electrical bias which removes the passivation layer in a local area around the contact. The chrome in this region becomes chemically active and begins to dissolve. This active region serves to electrically bias adjacent passive regions to a lower potential in a manner similar to that of the active metal contact thus causing them to also become active. In this manner, the entire connected area of a chrome film is made active and dissolves while those areas not in electrical contact remain passive and do not dissolve.

Furthermore, the activity of the cerium-based etches previously mentioned and which are commonly used for etching chrome films may be inhibited by a suitable electrical bias, such as may be caused by contact with copper while both metals are in the etch. Such electrical protection extends over a portion of the chrome film whose extent is determined by the voltage drops in the film that result from current flow to the protective contact. The size of the protected area may be controlled by varying factors, for example, film properties such as resistivity, or etchant properties such as concentration. Multiple protective contacts can be used to provide overlapping regions of protection. These techniques may be used to minimize voltage variations in the films and protection of a full-size mask can be readily accomplished. As will be readily appreciated by those skilled in the art, electrical biases could be applied to a wide variety of metals, in addition to chrome, on low conductivity substrates in appropriate electrolytes to produce patterns toned as desired using this electrical isolation technique.

Although these aspects of the present invention are explicitly exploited in the embodiments described using wet etching, similar results may be obtained for plasma based etching or physical sputtering in which the dry metal surface containing the electrically isolating outlines may be toned in a similar way by application of different voltages to the various electrically isolated features causing charged particles in the plasma to be attracted to or repelled from the biased regions.

Several characteristics of ECBFL will be appreciated by those working in the art. For example, it is implemented easily for patterns of simply-connected

features, i.e., features with one surrounding external boundary and no internal boundaries, with all of these features surrounded outside their boundaries by a single, common area in which all points are connected together. Such patterns may be obtained in chrome films on insulating substrates by, for example, making contact, in the common area, with Al or Cu as described. In many cases, ECBFL can also be implemented for multiply-connected features, i.e., features having internal boundaries. For a chrome layer on an insulator, patterns of multiply-connected features in a common background can be written completely when necessary for the "positive" case, i.e., the case in which the common area is removed, of ECBFL by exposing the appropriate internal areas of each feature as well as the external perimeter and removing these areas, for example, in the first etching procedure. The common area is removed in the second etching procedure as previously described.

It would be desirable, however, to have an addressable means to treat more general patterns of features. For a chrome layer on an insulator, one such means comprises outlining all features by etched trenches and then applying Al or Zn overlayers to a small portion of each feature whose removal is desired. After this step, which may be termed "decorating", the structure is immersed in dilute HCl and the decorated features etch because the metal decorations remove their passivity. This procedure is more complex since a separate lithographic step is required to produce the decorations. However, the simpler process described for patterns of simply-connected features is already quite useful because many patterns, such as individual levels of integrated circuits, are or can be made to be of this simple type.

There are several additional characteristics of Brush Fire Lithography which are advantageously mentioned. In the ECBFL embodiment described and in many other embodiments of BFL, the first etch which delineates the feature perimeter is the critical etching step for linewidth control just as it is in, for example, the usual master mask fabrication process. By contrast, there is little possibility of either over- or under-etching in the second larger area etch procedures since the trenches act as very effective stops. Also, in Brush Fire Lithography only relatively fine lines are written for a pattern which may contain numerous feature shapes and sizes. Improved precision in the pattern may result because some processing steps, such as resist development or wet etching, often yield results which vary with feature size.

Further, the occurrence of defects in BFL has different qualitative aspects than it has in conventional lithography. In ECBFL, a feature of a pattern may be obliterated if there is a point defect on the perimeter of the feature which connects it electrically to a neighbouring feature. If necessary, problems associated with such defects may be alleviated by, for example, drawing double width outlines on large features. However, several types of defects that are ordinarily detrimental with conventional lithographic techniques, for example, a dust particle on the

the surface of the material or its interstices. Propagating phenomena might comprise electrical or magnetic fields, heat, sound, or a phase change. The latter might comprise, for example, a change in crystal structure, melting, glassification, polymer cross-linking or chain scission. In many embodiments, the spread of the substance or phenomenon can be limited by removing the material at the feature boundaries. However, alteration of the material properties at the boundaries may also be used to control the toning process.

Although the embodiment described specifically relates to semiconductor integrated circuit or other micro-circuit fabrication, the method described may be used in other fields which generate patterns on substrates. For example, it will be readily appreciated that the production of hard copies and displays might be facilitated by the described method.

Other embodiments are contemplated. For example, the perimeters of the feature may be written in a positive resist and the resist then developed to form trenches outlining the features. Metal may be evaporated at an angle so that some portions of the trenches are not coated, for example, the bottoms. The resulting metal film comprises features which are electrically isolated from each other by the resist trenches, and which can then be toned by ECBFL or other toning procedures. The resist left exposed by the toning of the metal film can be removed by plasma etching or other techniques and the substrate may then be modified.

In yet another embodiment of the invention, two layers of positive resist may be deposited on a substrate. The features may then be written in outline as previously described and the resist developed. For some selected features, a heavy radiation exposure is then made at points within the outlines. This exposure is sufficiently intense to cause both of the resist layers to be rendered insoluble in those regions. A solvent is then used to dissolve all of the lower resist layers except for the insoluble regions, thereby causing the resist in the features without the interior heavy exposure to be removed. The resulting structure may be used, for example, as a mask for ion implantation or other directional processes that modify the substrate.

CLAIMS

1. A method for patterning material on a substrate, said material comprising radiation sensitive material, comprising the steps of defining, by exposing to radiation, at least portions of the material which forms the perimeters of features of said pattern, said defining producing radiation exposed first areas having characteristics differing from those of nonradiation exposed nonperimeter second areas, and toning said material, the extent of said toning being limited by said first areas.
2. A method as claimed in claim 1, in which said material further comprises an electrically conducting layer between said radiation sensitive material and said substrate.
3. A method as claimed in claim 2, in which said radiation sensitive material comprises a resist.
4. A method as claimed in claim 3, in which said radiation comprises electromagnetic radiation.
5. A method as claimed in claim 3, in which said radiation comprises a particle beam.
6. A method as claimed in claim 5, in which said particle beam comprises electrons.
7. A method as claimed in claim 3, in which said defining step further comprises developing said resist and thereby exposing portions of said electrically conducting layer.
8. A method as claimed in claim 7, in which said electrically conducting layer comprises a metal film.
9. A method as claimed in claim 7, in which said defining step further comprises removing those portions of said electrically conducting layer exposed by said developing step.
10. A method as claimed in claim 9, in which said electrically conducting layer comprises chrome.
11. A method as claimed in claim 7 or claim 9, comprising the further step of stripping said resist.
12. A method as claimed in claim 11, in which said toning step comprises selectively biasing a portion of said electrically conducting layer and immersing in an etchant.
13. A method as claimed in claim 10, in which said toning step comprises contacting a portion of said chrome with a metal and immersing in an etchant.
14. A method as claimed in claim 13, in which said metal comprises Al and said etchant comprises HCl.
15. A method as claimed in claim 13, in which said metal comprises copper and said etchant comprises a cerium based chrome etch.
16. A method as claimed in claim 9, in which said toning step comprises preferential etching.
17. A method as claimed in claim 9, in which said toning step comprises anodizing.
18. A method as claimed in claim 9, in which said toning step comprises electroplating.
19. A method of patterning substantially as hereinbefore described with reference to the accompanying drawings.

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